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A SYSTEMATIC APPROACH TO PRIORITIZING WEAPON SYSTEM REQUIREMENTS AND MILITARY OPERATIONS THROUGH REQUISITE VARIETY

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The 21st century U.S. military—being redesigned, developed and tested today—is driven by diverse global mission requirements and force modernization subject to fiscal constraint. The practical application of the theory of requisite variety is accomplished through development of an analytical framework for prioritizing force structure elements. It provides a systematic basis for assigning priority to research, development, production, and operational activities. Requisite variety ensures warfighting effectiveness subject to a variety of different mission requirements and budget constraints. The authors use a game-theoretic model to emphasize the importance of requisite variety in weapon system prioritization and operational decision making. They outline, define, and provide examples of three concrete approaches to increasing the variety available to a military commander—regulation, information, and variety catalysts. And they reinforce the distinction between qualitative and quantitative variety in military systems and operations. They further examine the framework through an Army advanced warfighting experiment, which leads to important results and considerations with respect to requirements determination, weapon system prioritization, and battlefield operations.

As it heads into the 21st century, the U.S. military is driven by two divergent factors (Figure 1): diverse global mission requirements, and force modernization subject to fiscal constraint.

Regarding the first factor, the military continues to fulfill mission requirements around the world, and it must remain prepared to deploy, in force, literally at a moment's notice. Although there is no

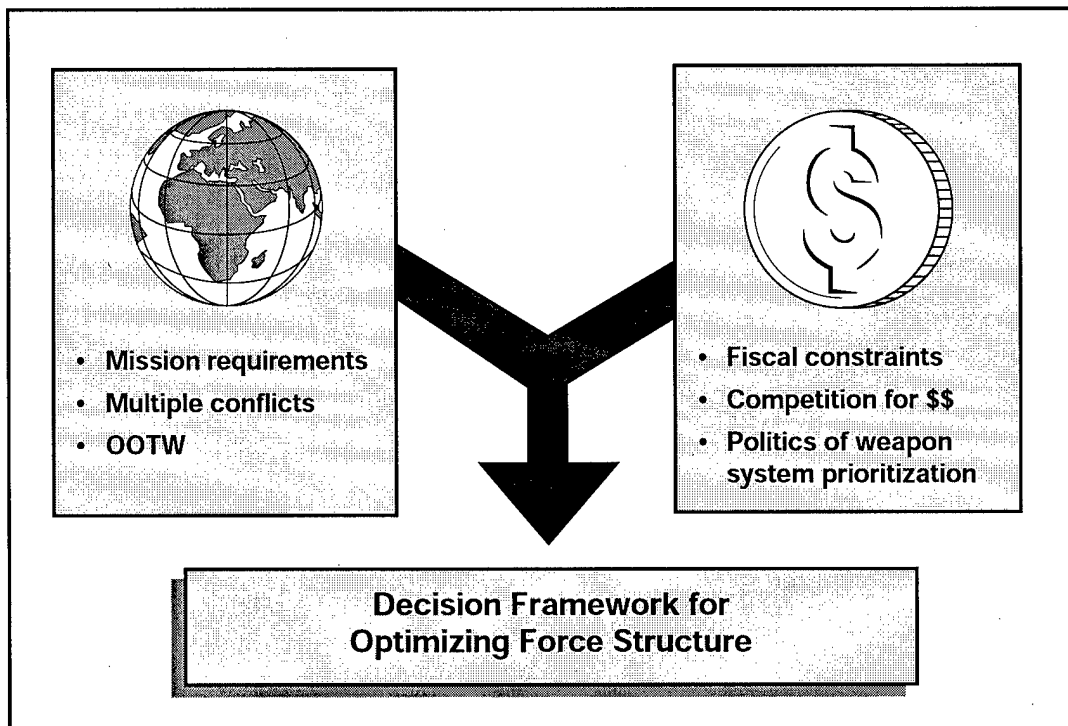


Figure 1. Motivation for the Study

longer a single, galvanizing threat such as the former Soviet Union, we observe an increasing likelihood of forces deploying to multiple, simultaneous regional conflicts. Missions are expanding to include operations other than war (OOTW), which can require a different set of skills and assets than those designed and used for intensive conflict. For example, the strict rules of engagement for peacekeeping missions could require a unique set of riot control weapons. A former Service Secretary has commented on this situation (West, 1997): "In the past, [we] trained primarily to fight and win large-scale conflicts; now we must prepare to meet a wider range of contingencies at all levels of the operational continuum."

The result is that U.S. military forces face greater demands than ever before, across a wide spectrum of threats that are

globally dispersed yet temporally confined. In short, the requirements have never been so demanding and of such wide variety.

Moreover, existing military assets are aging and require modernization to catch up with the quantum technological advances of the past two decades, particularly those involving information technology. But modernization of a responsive global force represents an expensive proposition. This expense is compounded by the increased variety of the expanding military mission noted above. Concurrent with diverse and demanding mission requirements, the United States faces a severe fiscal constraint and has significantly decreased defense spending. Competition for dwindling defense dollars is intense, as modernization must compete with readiness, armor with air defense, the Army with the

Navy and Air Force, and so forth. Further, the politics of weapon system prioritization are equally intense. As a result, the risk of misallocating scarce military resources to the wrong mix of systems has never been greater. The potential consequence of this situation is clear; when the need for warfighting arises, the correct mix and number of forces may not be available within the time frame required for decisive action.

This article demonstrates practical application of the theory of requisite variety through the development of a decision framework for prioritizing force structure. Although the scope of this article is quite broad and applicable to the entire joint warfighting community, we make the framework and associated concepts concrete by focusing on the Army, which arguably is most affected by expanding mission requirements such as OOTW. We will examine the current requirements determination process and conceptual doctrine the Army proposes to use in the 21st century. With this background, we apply the theory of requisite variety to develop a conceptual framework for analyzing the mix of weapon systems programs and operational forces. The framework provides a systematic basis for prioritizing research, development, production, and operational activities to ensure military warfighting effectiveness subject to a variety of different mission requirements (e.g., OOTW, peacekeeping, war) and severe budget constraints. We then examine the model by assessing this conceptual framework in terms of an Army advanced warfighting experiment, and then present conclusions and recommendations for the military leadership.

CURRENT REQUIREMENTS DETERMINATION PROCESS

To address the complexities of 21st century warfare, the Army has implemented a new requirements determination process and developed unique concepts for land combat called Force XXI operations. The new requirements determination process investigates many promising advances in science and technology, in addition to meeting operational deficiencies identified through mission area analysis. The process depicted in Figure 2 begins with the training and doctrine command (TRADOC) vision, which is translated into required future operational capabilities (FOCs). FOCs are intended to provide a warfighting focus for the Army's science and technology investments. One set of FOCs is written for each of the Army's battle laboratories and encompasses the battlefield dynamics for which each lab is responsible. The battle labs (along with TRADOC combat developers) use integrated concept teams (ICTs) to transform FOCs into solutions across the domains of doctrine, training, leader development, organization, materiel, and personnel. These solutions are examined and tested through live, virtual, and conceptual warfighting experiments. Feedback from the experiments is used to further define and refine the product until a firm

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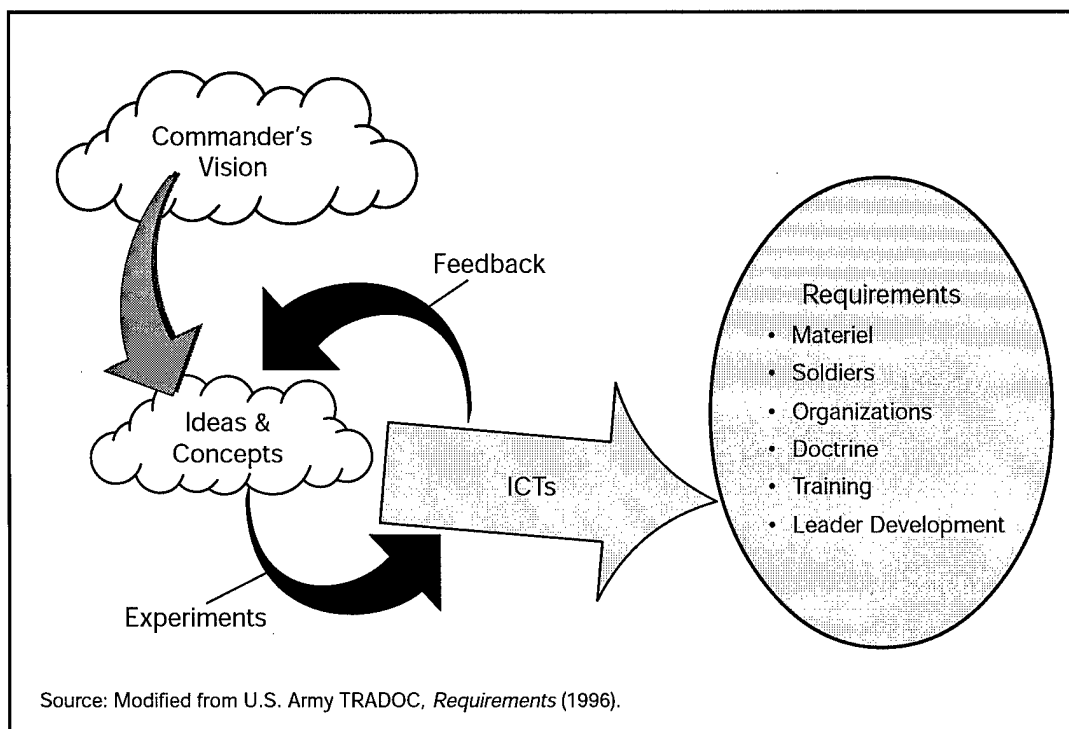


Figure 2. Army's Requirements Determination Process

requirement emerges (U.S. Army TRADOC, 1996). As noted above, the number and diversity of such firm and well-understood requirements continues to multiply.

The requirements determination process is designed to be flexible. ICTs include personnel from a broad spectrum of disciplines and have the potential to facilitate a smooth transition to the integrated product teams (IPTs) used to manage materiel programs. But the resources needed to purchase all materiel requirements are rarely there—especially in the quantities specified by commanders. The result is that key doctrine and tactics deemed necessary cannot be fulfilled. We believe there are numerous opportunities to leverage the theory of requisite variety during this process to help solve the problem.

Plans for Force XXI operations make numerous direct and indirect references to the need for variety in our forces. For example, they call for knowledge-based operations, which exploit information technology and leverage other technological opportunities to achieve a new level of effectiveness in joint warfighting, while minimizing exposure to casualties. They also call for soldiers themselves to become more versatile, capable of performing a number of different missions, often simultaneously. They emphasize multidimensional operations—attacking the enemy across myriad spectra, decisive operations, and even, simultaneously, humanitarian relief. Such features require commanders on the ground to be equipped with a wide variety of diverse weapon systems and modern assets, not just a large number of existing ones.

Unfortunately, the military has not articulated this need for variety well, and it has consequently suffered considerable criticism. For example, Army Force XXI operations have been criticized by some who believe the conceptual doctrine is too abstract, at the level of "Star Wars," and the Army has not adequately explained its vision for warfighting experiments to Congress (General Accounting Office, 1995). The theory of requisite variety provides the kind of intellectual foundation and approach to effectively articulate this need, as well as to assign priority to, quantify, and justify its integrated weapon systems, modernization plans, tactics, and doctrine.

REQUISITE VARIETY

The theory of requisite variety was developed through studies of complex

system dynamics (Ashby, 1956). Researchers such as Ashby observed that as systems become more complex, the variety of their behaviors proliferates. Further, in order to control a complex system, the variety of responses built into the control mechanism must be at least equal to the variety of the system itself. In other words, the variety of the controller must equal or exceed that of the controlled, and the degree of variety sufficient to control a particular system is defined as requisite variety. Following Ashby (p. 208), only variety can control variety.

The theory of requisite variety has a direct military application. For example, it directly supports the Army concept of dominant maneuver. In the simple case shown in Figure 3,¹ the friendly commander serves as the control mechanism and the "enemy"(situation) represents the system to be controlled. Examples of this structure are coalition forces seeking to

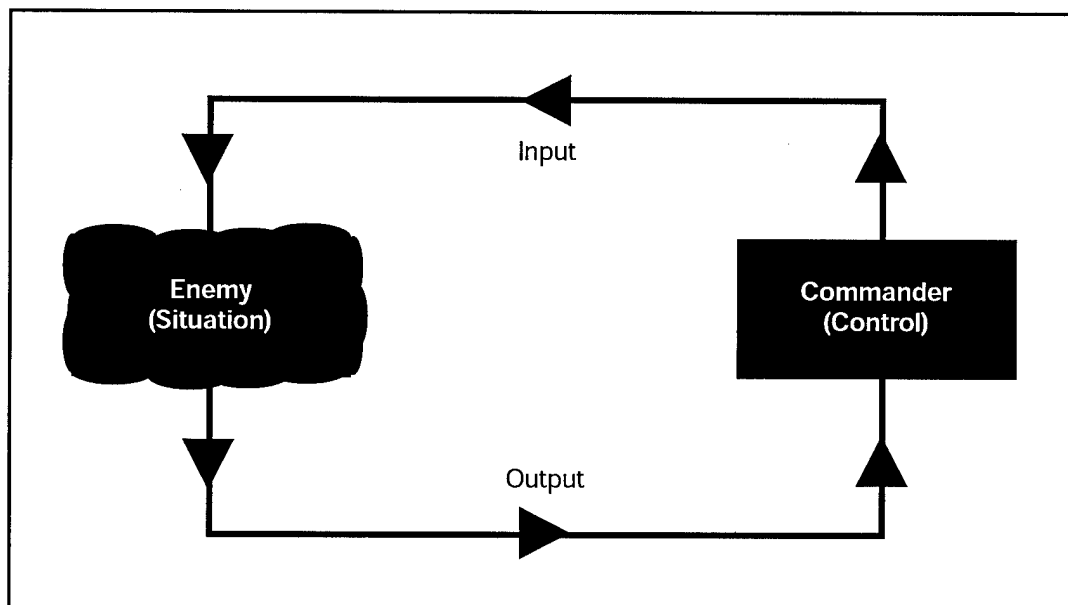


Figure 3. SystemControl

control Iraq's access to weapons of mass destruction, and peacekeeping forces working to control ethnic killing in Bosnia. Each action taken by the enemy is perceived by the commander, who uses the resources and options available to counter such actions and control the system. As the enemy grows in capability, the variety of available actions proliferates. To control this increasingly capable enemy, as a minimum, the commander must at least be able to counter enemy actions. But to dominate the enemy, the commander requires a variety of weapons and tactics that exceeds the enemy's ability to make an effective, timely response.

We illustrate requisite variety in a game-theoretic context as shown in Table 1. Although this example is simple, the theory and practical application scale very well to support military planning and weapon system prioritization up to the Army level and beyond (e.g., the Department of Defense, the North Atlantic Treaty Organization, coalition forces). The friendly commander's courses of action (COAs) are listed on the left side of the table. In this example, they include an armor battalion (AR BN), an attack helicopter battalion (ATK HEL), and an air defense task force (AD TF) capable of defeating helicopters and tactical ballistic

missiles. The enemy commander's COAs are listed along the top. They include an attack helicopter squadron (ATK HEL), a tank regiment (TK REG), a motorized rifle regiment (MR REG), and a tactical ballistic missile regiment (TBM). As noted above, there is no hard limit to the number of COAs and mix of participants (e.g., Army/Navy, U.S./foreign military, war/OOTW) that can be analyzed through this technique. We now describe the simulated battle or engagement outlined in Table 1.

Both commanders are assumed to be situationally aware (i.e., they can see the table) and the game-theoretic rules are as follows. The enemy is allowed to make the first move by selecting a COA, and thus, a particular column. The friendly commander, observing this selection, then chooses a COA in response (i.e., a particular row). Recent military experience is replete with examples of this "wait for the enemy to move" approach (e.g., Iraq invades Kuwait; Serbia seizes control of Bosnia). The outcome of the encounter is determined by the intersection of the selected row and column and is represented in the table by bold, italic letters. Let's say, for example, that if the outcome is *a*, the friendly commander wins the engagement. If it is not *a*, the friendly commander loses.² Clearly the specific

Table 1. Matrix Model 1 of Ashby's Law

	<i>ATK HEL</i>	<i>TK REG</i>	<i>MR REG</i>	<i>TBM</i>
AR BN	b	<i>a</i>	c	d
ATK HEL	c	c	<i>a</i>	b
AD TF	<i>a</i>	b	b	<i>a</i>

table entries would vary for each theater of war or operations.

It is straightforward to show in Table 1 that the friendly commander possesses requisite variety to control the enemy. If the enemy moves first with attack helicopters (ATK HEL), for example, the friendly commander can counter with his air defense task force (AD TF). Similarly, if the enemy moves first with a tank regiment (TK REG), for example, the friendly commander can counter with armor (AR BN), and so forth. Regardless of the enemy COA, the friendly commander possesses sufficient variety to choose a COA and force the outcome to become *a* (therefore he can win), regardless of the enemy COA selected. And recall that the friendly commander even allows the enemy to move first. Thus, the friendly commander can dominate the theater because he possesses the requisite variety of forces and assets.

At first glance, this military application may appear obvious or even simplistic. A commander might state, for example, "Of course if you give me more tanks or more soldiers I will defeat the enemy; I will overpower him with numerical superiority." However, a careful distinction must be made between numerical superiority and the variety of options available to a commander. Numerical superiority, or quantitative variety, is just that—the number of soldiers, number of weapon systems or other factors used to determine a superior force. This was long the basis of Soviet weapon systems prioritization. Particularly when projecting force abroad, however, numerical superiority cannot always be ensured.

Alternatively, the nature of requisite variety is more qualitative. It is less concerned with aggregate totals than the mix

of different types and capabilities of soldiers, weapon systems, and tactics, as well as various configurations and temporal patterns in which they can be employed. Thinking back to the Gulf War, for example, most experts seem to agree that satellite reconnaissance, broadband communication, fast armored maneuver, and Patriot air defense proved to be more instrumental to decisive victory than the number of tanks and soldiers in theater. Indeed, Gulf War experience supports our arguments by suggesting that the commander with a sufficient mix

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(i.e., requisite variety) of COAs can even defeat an enemy with numerical superiority.³ This point is further illustrated through the simulated battle or engagement outlined in Table 2. This time the friendly commander has greater numerical quantities of some weapons than before (i.e., greater quantitative variety): two armored battalions and two infantry battalions. However, his qualitative variety has actually decreased because he no longer has an attack helicopter battalion or air defense task force. Now the table shows the friendly commander can no longer control the situation 100 percent of the time. For instance, the enemy can choose two COAs—attack helicopters (ATK HEL) and tactical ballistic missiles (TBM)—and force the outcome to be something other than *a* (i.e., force the friendly commander to lose the engagement). Despite having greater numbers of armor and infantry, the friendly

Table 2. Matrix Model 2

	<i>ATK HEL</i>	<i>TK REG</i>	<i>MR REG</i>	<i>TBM</i>
AR BN	b	<i>a</i>	c	d
AR BN	b	<i>a</i>	c	d
INF BN	c	b	<i>a</i>	c
INF BN	c	b	<i>a</i>	c

commander lacks the requisite variety to counter and control the enemy.

Clearly, the concept can subsume Army operations to include joint warfare. For example, ADM Joseph Prueher, Commander-in-Chief, U.S. Pacific Command, recently made an indirect reference to requisite variety (Prueher, 1996):

...each service (Army, Navy, Air Force) brings a unique capability to the battlefield. It is similar to a football team. You can't have a team with all fast receivers with good hands. In addition you need strong, relatively slow linemen, defensive specialists, and a quarterback. This is the nature and strength of joint warfare.

With this background, we turn to the question of how to determine requisite variety for a military force, putting the framework to practical use.

APPLIED MILITARY FRAMEWORK

Our scheme to operationalize the concept of requisite variety is based on some

concrete, well-understood methods for increasing commanders' ability to dominate the enemy. Consider the relatively simple model outlined above, in which a commander is responsible for controlling a system. Figure 4 shows an expanded model of the system embedded in its environment (depicted by the rectangle that encompasses the situation). This rectangle is drawn with dashed lines to indicate that, in real life, the environment is fluid, rather than static. Highlighted in the model are three factors affecting a commander's variety of action: regulation, information, and variety catalysts.

REGULATION

External factors exert forces on the system beyond the commander's control, and regulation can affect variety either positively or negatively. On the positive side, regulation (beyond the commander's control) can be used to limit the capabilities of current enemies or potential threats. International treaties (e.g., Strategic Arms Limitation Treaty, Nuclear Non-Proliferation Treaty), postwar disarmament (e.g., of Germany and Japan) and arms-inspection programs (e.g., in Iraq) represent examples of positive regulation. Notice

the subtlety of such regulation. It serves to augment the commander's variety, not by increasing his COAs, but by decreasing the variety required for him to control the enemy.

As noted above, the opposite, negative effect of regulation occurs when the commander's mission portfolio is expanded (e.g., to include OOTW). These effects actually increase complexity and therefore exacerbate the need for variety in the friendly system. So long as the United States continues to use military forces to counter natural disasters and conduct OOTW, such lack of system regulation increases the variety of missions the Army has to perform.

INFORMATION

Information can be used by the commander to reduce the uncertainty of a system. Figure 4 shows numerous enemy COAs flowing toward the commander. To begin an engagement, the enemy selects one of these COAs.⁴ But until the commander can see or sense which COA is selected, he must consider and plan for every likely option available to the enemy. For example, the commander in theater must deal with the uncertainty of when, where, and how (even if) an enemy might strike. Shown as a funnel in Figure 4, information acts as a filter to reduce uncertainty (e.g., sensing enemy armor movements) and to expedite the proactive

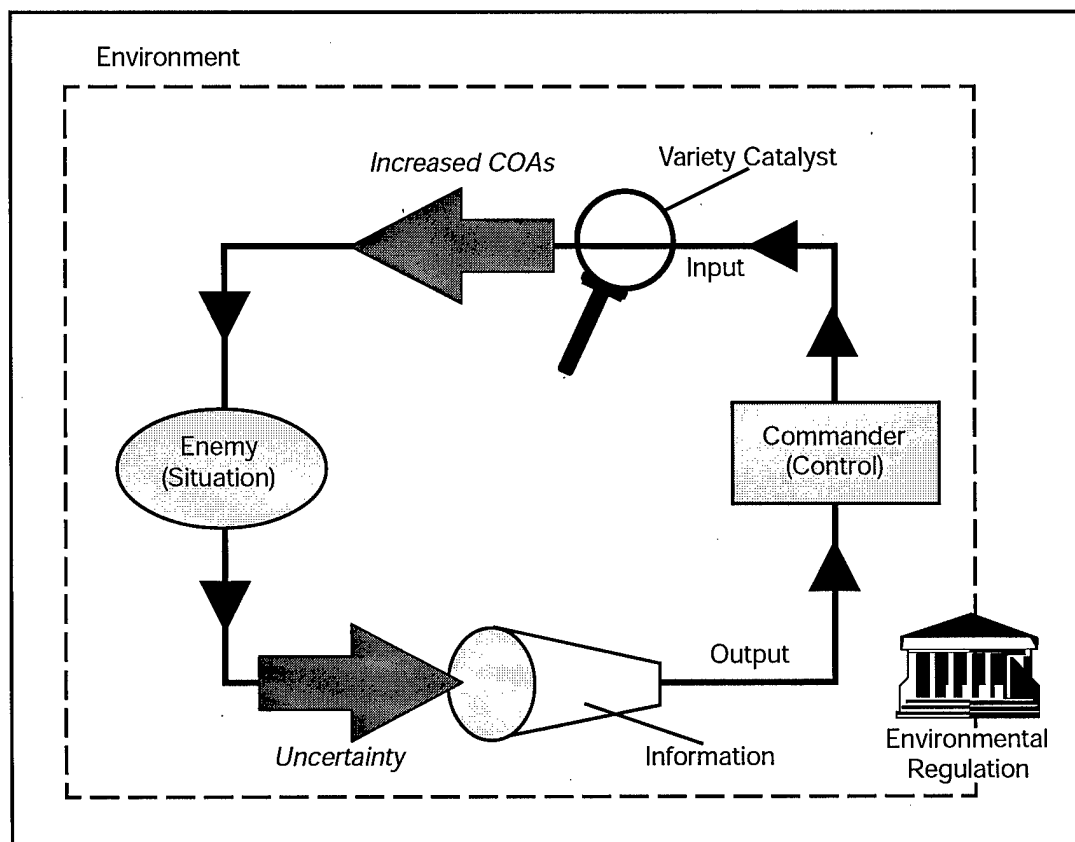


Figure 4. Framework for Providing Requisite Variety

use of counter actions available to the commander (e.g., long-range air mobile strikes). Indeed, such information dominance represents a key aspect of Force XXI operations.

Information also benefits the units and soldiers that are led by the commander. Some call this the "fog of war." To the soldier on the ground, it is the confusion or uncertainty of where he is on the ground, where the other units are located, and what is happening on the battlefield. Information—situational awareness—on the digital battlefield reduces this uncertainty, informing soldiers where they are, where their buddies are, and where the enemy is.

It is important to understand, however, that information does not reduce or limit the enemy's COAs. Rather, it reduces the uncertainty of the situation and helps the

"Information also benefits the units and soldiers that are led by the commander. Some call this the 'fog of war.'"

commander to anticipate and counter them responsively. This analysis points to command, control, communication, and intelligence (C³I)

assets as principal tools to exploit information dominance. Integrated C³I assets reduce the time it takes to observe the enemy, orient friendly forces, and decide what action to take, for example.

VARIETY CATALYSTS

The analysis above also points to mobility assets, which complement information by reducing the time required to take action. As with information, mobility has no direct effect on enemy COAs, but by

increasing mobility, the commander's COAs (i.e., variety) increase. Thus, the reader should appreciate that relative variety is key to this analysis. Moreover, mobility represents an example of the most potent dimension associated with this framework: variety catalysts. As depicted in Figure 4, variety catalysts directly increase the number of COAs available to the commander. They include changes in doctrine, training, organizations, leadership, personnel and materiel. Figure 4 shows a set of COAs flowing from the commander to the enemy. Variety catalysts, depicted as a magnifying glass, amplify the number and types of COAs and increase the commander's variety. As noted above concerning materiel solutions, there are two ways to catalyze variety: quantitatively and qualitatively.

Quantitative catalysts. Increasing quantitative variety means increasing the number of the same types of weapon systems, soldiers, or units. This method relies on massive force structures to overwhelm the enemy. It is not concerned with different types or kinds of weapon systems, but entirely with the quantities of each. By increasing the number of weapon systems, variety expands due to the increased number of combinations available to the commander. Consider ADM Prueher's football analogy from above. Quantitative variety is like a team fielding 22 players against the opponent's 11. Think of all the different combinations of pass routes available to the quarterback with nine wide receivers, for example.

While this time-tested focus on quantitative variety may appear attractive, it has two distinct disadvantages. The first is cost. In today's environment, the DoD has little chance for budget increases.

Rather, military commanders are now accustomed to making do with less. Even so, opportunities to increase quantitative variety are not limited to just "buying more stuff." Most notably in the combat service support domain, the effective number of weapon systems (e.g., measured by tactical aircraft sortie rates) can be increased by reducing repair time, decreasing mean time to repair, and similar logistical interventions. The second disadvantage is that numerical superiority does not directly translate to victory on the battlefield. Earlier we saw that the friendly commander, despite having superior numbers, could not completely dominate the engagement because he lacked the necessary attack helicopters and air defense assets. In many instances, quality, not quantity, is the dominant factor in theater.

Qualitative catalysts. Qualitative variety concerns the diversity of actions available to control the system (e.g., commander COAs). Returning to our football analogy, to increase qualitative variety, a team could recruit players with different skills. Some may be fast runners and catch well, while others are big, strong, and very effective on the line, with still others who may kick well, and so forth. Note also by analogy that modern-era strategies and play selections require all players to be smart and well-trained. The Denver Broncos won Superbowl XXXII despite having a relatively "small" offensive line, for example, in part because of the variety of effective plays it could execute. A different option is to recruit players that are multitasked, athletes able to play multiple positions and roles well (e.g., running backs who can throw passes, blocking receivers, quarterbacks able to

run). Such multitasked players tend to be quite expensive, however.

Regarding military weapon systems, there are three primary approaches to increasing qualitative variety. The traditional approach is to build many different types of weapon systems (e.g., service-unique aircraft or trucks). This is analogous to recruiting specialist players with different skills. The use of current and developing space

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technologies, for example, opens up an entirely new set of options for the commander who can sense and observe from the ultimate "high ground." History shows that the disadvantage of this option is cost. Different, specialized weapon systems require unique inventories of spares, separately trained mechanics, idiosyncratic ammunition, and specialized operator skills, the life-cycle cost of which is relatively high.

A second approach—adapted from commercial industry—is to design families of weapon systems. For instance, a Bradley chassis can be used not only for an infantry fighting vehicle, but also for an air defense artillery system, and the Army currently does this with the family of medium tactical vehicles, which share a common chassis but are available in different cargo variants (e.g., materiel handling, dump, tractor, wrecker, vans). Likewise, the Navy envisions its next generation of surface combatants (SC-21) in terms of a family of ships, much C³I

software is now developed into product lines, and so forth. Each individual system in a family or product line has a mix of common and peculiar elements in this approach. But this approach also suffers some of the same limitations, in that specialized parts, mechanics, operators, and the like could be required for each peculiar portion in a system family or product line.

A third approach to increasing qualitative variety is through weapon systems capable of performing multiple missions. This is similar to recruiting a multitasking player. For example, one weapon system could be developed not only to shoot artillery fire, but also to destroy enemy aircraft and

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have enough mobility and direct firepower to be used as an infantry fighting vehicle. This third approach differs from that above

in that both the air-defense and infantry missions, for example, are accomplished by the same vehicle, whereas two similar-but-different vehicles (sharing common parts) are required in the family or product-line scheme above. This option also has disadvantages, for building complex weapon systems with multiple roles is difficult and sometimes costly. Not only does operation near the edge of the state of the art often greatly increase cost and performance risk, it can also have a deleterious effect on reliability. Norm Augustine described this as the Law of Insatiable Appetites: "The last 10 percent of the performance sought generates one-third of the

cost and two-thirds of the problems." He continues (Augustine, 1983):

Soon DoD will build an aircraft that is so expensive that it will have to be shared by the Services. The Air Force will use it for three days, the Navy for two, and the Army and Marines will use it half the time for the other two days of the week.

Another disadvantage is the risk that one of these super systems would be destroyed. One artillery round or even a simple software virus could knock out a considerable amount of firepower. It would be like our multitasking football player suffering an injury which prevents him from playing.

Other areas such as doctrine, organizations, training, and recruiting can also increase the qualitative variety of a military force. While they may not directly increase the number of COAs available to the commander, they magnify variety by enabling a commander to more efficiently use his resources. Continuing our football analogy, these latter areas would pertain more to the coaching staff, training facilities, and draft strategies than the football players themselves, but in a budget-constrained environment such as that faced by the DoD, one is compelled to investigate every viable opportunity, particularly those that increase variety at reasonable cost.

EXAMINATION OF THE FRAMEWORK

We have used the applied military framework to articulate three concrete

methods for increasing the commander's ability to dominate the battlefield: regulation, information, and variety catalysts. Clearly, all three alternatives can be combined to compound synergistic effects, but the optimal mix is dependent on the specific set of requirements (e.g., war or OOTW, desert or jungle, pre-positioning or amphibious assault) and subject to budgetary constraints. This applied military framework provides the analytical structure to objectively conduct the necessary requirements and tradeoff analyses.

The framework is examined by applying it to an Army advanced warfighting experiment (AWE). The intent is to analyze the exercise from the perspective of our requisite variety framework. The exercise, conducted from July to December 1995, was a general officer working group project sponsored by TRADOC. The goal of the exercise was to determine Force XXI requirements, structure, and conceptual doctrine for use in follow-on live and virtual exercises. We chose this particular exercise because it served as the foundation for many TRADOC Force XXI conceptual doctrine publications and research studies. The objective of the exercise was to build upon the early Force XXI concepts and produce:

- the division operations and organization manual for Force XXI units;
- the warfighting tasks and tactics, techniques, and procedures (TTP) for Force XXI units; and
- the how-to-fight manual for the experimental force (EXFOR⁵).

A major regional contingency set in the 21st century served as the scenario for this exercise. The friendly forces consisted of a Force XXI division (e.g., M1A2 tanks, M2A3 infantry fighting vehicles, LOSAT antitank systems, future scout vehicles (FSV), and *Comanche* helicopters). This notional division was assigned the dominant mission of the corps' decisive operation. The opposing forces consisted of a combination of high- and medium-technology enemy divisions (e.g., T72/T80 tanks, BTR 80 infantry vehicles, HIND D/E/F helicop-

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ters). It is interesting to note the opposing forces outnumbered the Force XXI division; that is, the "enemy" possessed superior quantitative variety.

The AWE supports many aspects of our conceptual framework. For example, the general officer working group recognized that without requisite variety, the Force XXI division would be unable to conduct decisive operations; that is, the division would not be able to dominate the battlefield. The lack of requisite variety in this exercise can be traced to two factors. First, using TRADOC vernacular, the Force XXI division did not have the "assured capabilities" required for the operation. Two examples involve mobility assets for the light brigade and air defense assets. The ideal plan of attack included the use of light infantry in combination with armor

forces. But the division lacked the airlift or truck capability needed to fully exploit this option. The resulting mobility differential made it difficult to synchronize infantry with armor and left infantrymen vulnerable to counter-attacks with no capability for self-extraction. In addition, the extended range of the operation left the division vulnerable to air attacks and surveillance. Because the Force XXI division lacked sufficient air-defense assets, the enemy could exploit this weakness. In other words, if the enemy chose this COA, the friendly commander did not have the requisite variety to control the situation.

Second, the corps operation plan prescribed tasks that limited how the 25th (Force XXI) Division intended to fight. For example:

- Corps planned fire strikes on the enemy's 15th Tank Division (TD) and 3rd Motorized Rifle Division (MRD) prior to the 25th Division contact with the enemy.
- Corps employed dynamic obstacles to fix the enemy's 15TD and 3MRD.
- Corps assigned an aviation brigade to attack the lead regiments of the enemy's 15TD and 3MRD.

This regulation from higher headquarters limited the options available to the friendly commander, because these actions were in his area of operations. The examples show that external regulation, in this case, reduced the number of COAs available to the friendly commander (i.e., reduced his qualitative variety). Our framework suggests that less (negative)

regulation could reduce this effect. Further, (positive) regulation could reduce the complexity of missions the friendly commander is required to perform, thereby decreasing the variety of the situation to be controlled. For example, higher headquarters could have reduced the threat of enemy second-echelon divisions by conducting air strikes beyond the 25th Division's area of operations. The group of general officers deemed this point to be very significant; one of their key findings was that higher headquarters must reduce the prescriptive tasks dictated to subordinate units.

This examination of the AWE supports two important aspects of our framework. First, variety in the friendly force is important. Without requisite variety, for example, the 25th Division could not conduct decisive operations. Second, higher command levels must consider the impact of external factors and strive to regulate these factors. Constraining commanders on the ground, for example, can actually limit warfighting effectiveness.

Given these observations, one might surmise the 25th Division had an unsuccessful day on the battlefield, but this was not the case. The division was highly successful because of the information available. The general officer working group realized that information dominance was a valued commodity that had to be planned for and efficiently used to be effective. Integrated C³I assets such as satellites, human intelligence, electronic warfare, and radar systems reduce the uncertainty of the enemy situation. This situational awareness was leveraged through the use of highly mobile assets (e.g., helicopters given quick attack missions) and long-range precision strikes to proactively

shape the battlefield and dominate the enemy. They attacked the enemy in numerous directions from dispersed locations. By integrating C³I and mobility assets, the general officers achieved synergistic results. These assets allowed the 25th Division to attack in a variety of patterns by leveraging information.

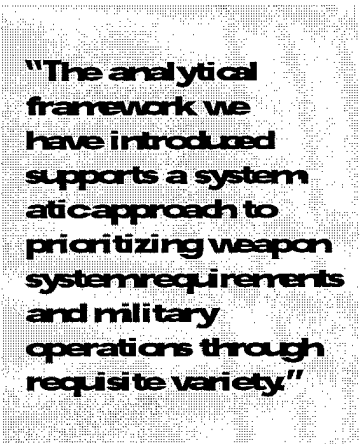
In summary, the AWE involved all three aspects of our framework for providing requisite variety: regulation, information, and variety catalysts. This helps portray how the concepts associated with requisite variety and our analytical framework can be applied directly to the military, and it highlights key elements of their use and utility in support of Army experiments involving its ideas for warfare in the future: Force XXI. This examination of the framework also reinforces the distinction between qualitative and quantitative variety and shows how even a numerically inferior force can prevail using regulation, information, and variety catalysts from the framework. In essence, we see that variety can serve as a proxy for military efficacy and provide some capability for explanation and prediction of differential results on the battlefield. Thus, our framework for requisite variety provides a language of constructs and method of analysis for robust and detailed effectiveness studies. And when combined with the many current techniques for cost analysis, this framework supports a novel, systematic approach to prioritizing weapon system requirements and military operations through requisite variety.

CONCLUSIONS

The analytical framework we have introduced supports a systematic approach to prioritizing weapon system requirements and military operations through requisite variety. This framework takes Ashby's Law, a relatively simple but underused theory, and applies it directly to the military. It shows that complex systems, including battles and engagements, can be evaluated through requisite variety, and the framework provides analytical constructs and guidelines for using variety as a proxy for, or predictor of, military efficacy. The military can first use the framework as a diagnostic tool to analyze the variety of

the system. For example, it can help assess what threats are to be faced and the diversity of missions that are to be performed, then help identify possible solutions using the framework to maximize the operational effectiveness of forces through the requisite variety construct. Cost can then be weighed against the possible solutions.

Further, the framework provides a common vocabulary to explain weapon requirements and the concepts of Force XXI to both Congress and the warfighters on the ground. It helps to answer many important and timely questions. For example, why is the military spending millions of dollars on high-tech equipment to digitize the battlefield? Why is the Army developing conceptual doctrine that seems



"The analytical framework we have introduced supports a systematic approach to prioritizing weapon system requirements and military operations through requisite variety."

more suitable for Luke Skywalker than Sergeant York? Our use of requisite variety can improve the quality of answers provided to Congress, the soldiers, and other concerned stakeholders.

Although the concept of variety may appear intangible, the analytical framework described in this paper outlines three concrete approaches to increasing commanders' variety for battlefield domination: regulation, information, and variety catalysts. Each of these has distinct advantages and disadvantages.

"Our use of requisite variety can improve the quality of answers provided to Congress, the soldiers, and other concerned stakeholders."

Optimally, a combination of the three alternatives should be considered for their synergistic effects, and when cost is combined

with variety (as a proxy for effectiveness) in the equation, this framework provides the analytical structure necessary to objectively prioritize weapon systems and evaluate military operations.

RECOMMENDATIONS FOR THE MILITARY

This work leads us to six recommendations for the military.

Incorporate variety as a factor. The most significant finding of this study is that variety can be a useful factor for prioritizing requirements for the future operational forces of the U.S. military. We have seen that future military forces face a diversity of threats and missions in a global environment with unprecedented complexities. The theory of requisite variety reveals that in order to control such complex systems, the amount of variety

in the control mechanism must equal or exceed that of the system being controlled. We recommend that each military service move to directly apply variety constructs such as regulation, information, and variety catalysts in its requirements determination process (especially during mission area analysis and analysis of alternatives). TRADOC should combine variety with cost as primary factors for prioritizing alternative weapon systems and force structures. All stakeholders including ICTs, IPTs, battle labs, and warfighters need to understand the concept of requisite variety.

Aggressively pursue intelligence on future threats. During the Cold War, the United States had very robust intelligence efforts to gain and interpret information about the Soviet Union. However, as defense spending has dwindled, so have these intelligence efforts. The United States should continue to pursue robust intelligence efforts focused on determining valid threats. Just as situational awareness decreases the uncertainty of the enemy situation to the friendly commander on the ground, identifying strategic threats can reduce the uncertainty at the national level. Without these intelligence efforts, it will be difficult to measure the amount of variety we need. The potential consequence is not having the correct mix of forces on the future battlefield.

Prioritize weapon systems. Given current financial constraints, the short-term military requirements should focus on C³I and mobility systems. Such assets appear to provide the best variety-to-cost ratio and may represent a requisite-variety bridge to 21st century warfare. As illustrated in the AWE, information reduces uncertainty in the system, and

mobility complements situational awareness to increase the variety of action for friendly forces. Modernization of other weapon systems, such as multirole fighting vehicles, can further increase force variety, but this approach portends to be quite costly. With the quality of intelligence assets that exist, the military can make great strides by simply re-engineering the process of obtaining and distributing information. Notice we do not argue for building all intelligence systems and no action systems. But neither should we neglect intelligence to support weapon system modernization. Either way, by putting all our eggs in one basket, we risk not having the requisite variety to conduct decisive operations.

Continue joint warfare. Using the capabilities of all the Services in joint warfare is an excellent, low-cost approach to increasing variety. The United States should continue to train and fight as a joint team, and efforts should be made to increase the connectivity of weapon systems and doctrine to achieve synergistic results with the expanding NATO and potential coalition partners. The variety of weapon systems in current inventories and arsenals of allied nations is substantial, and it augments our ability to attack and defend across multiple dimensions from either dispersed or close-proximity locations on the battlefield.

Reduce higher headquarters' prescriptive tasks to subordinate units. Prescriptive tasks from higher headquarters negatively regulate commanders on

the ground and limit their warfighting effectiveness. We observed this phenomenon with the 25th Force XXI Division. Following the technique of empowerment, higher headquarters should focus on what the requirements are, not how to perform them, and explicitly decide whether and how much to limit commanders' variety in theater.

Continue variety research. Our final recommendation is to continue this line of research to enhance and refine the framework developed in this paper. Toward this end, four topics for further study appear to have merit:

- Investigate alternatives to model and quantify the factor of requisite variety.
- Examine what impact requisite variety has on logistics in terms of life-cycle costs, schedule, and performance.
- Research different possibilities for variety catalysts.
- Explore how the conceptual framework for providing requisite variety can be applied to a weapon system program.

Research represents a prudent approach to developing new knowledge—especially when compared to trial and error on the battlefield—and the application of requisite variety to weapon system prioritization appears to be a timely, practical, and powerful topic for continued work along these lines.



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ENDNOTES

1. In order to simplify the system, we assume all the influences on the enemy are channeled through a single input and all effects are channeled into a single output.
2. A "win" in this example is defined as a clear and decisive victory. All other outcomes result in a loss. The various loss outcomes are represented in Tables 1 and 2 as b, c, and d.
3. Clearly, many factors contributed to success in the Gulf War (e.g., air strikes, tactical skill and savvy of commanders). Indeed, the presence of such a variety of factors strengthens the importance of our distinction between qualitative and quantitative variety.
4. Practically, the framework and analysis can scale to address any number of simultaneous enemy COAs.
5. The EXFOR is a Force XXI-equipped division located at Fort Hood, TX. The EXFOR is the unit that participates in the "digital" National Training Center rotations and other AWEs to test new concepts and equipment.